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SELECTING AND RANKING COST RESEARCH PROJECTS

This paper describes a systematic methodology to select and rank projects in support of the CAO cost research mission.

The paper is in two parts. Part 1 identifies a large list of candidate cost research projects, and their descriptions, which are divided into four categories: (1) Databases; (2) Cost Estimating Relationships (CERs) and Methods; (3) Models; and (4) Special Studies. Part 2 of the paper describes in detail a process for selecting the "best" set of projects within limited funding constraints using the Analytic Hierarchy Process (AHP) in conjunction with an Integer Linear Program (ILP). The process entails three major steps: (1) developing and evaluating a multi-criteria hierarchy; (2) determining the relative value of each potential project using the AHP method, where the relative values of "priorities" are based on factors such as urgency, affordability, payoff, and feasibility; and (3) selecting the "best" projects using ILP.

The decision process presented in this paper is a unique application of operations research decision theory which could be tailored to many decision-making tradeoffs that the DoD faces. A spin-off of this effort could be a useful tool for program management problems that transcend cost research planning.

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SELECTING AND RANKING COST RESEARCH PROJECTS

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Lewis S. Fichter
William H. Jago

JUNE 1993

Prepared for

THE TWENTY-SEVENTH ANNUAL
DOD COST ANALYSIS SYMPOSIUM

SELECTING AND RANKING COST RESEARCH PROJECTS

(New/Innovative Techniques in Parametric Cost Estimating)

Dr. William H. Jago

Dr. Lewis S. Fichter

The implementation of the Strategic Defense Initiative, now called Ballistic Missile Defense (BMD), requires developing capabilities to protect U.S. forward deployed forces, power projection forces, friends and allies, and the United States against ballistic missile attacks. Such protection now primarily involves ground-based systems and elements to ensure continuous global detection, track, and intercept of ballistic missiles and their associated warheads. U.S. Army efforts include coordinating with the Ballistic Missile Defense Organization (BMDO); conducting research, development, and acquisition of strategic and tactical systems to include: Theater and National Missile Defense elements; and developing appropriate technology bases. The role of research and development of the strategic systems is the responsibility of the U.S. Army Space and Strategic Defense Command (USASSDC). Within USASSDC, the responsibility for developing cost methodologies, models, databases, and Independent Cost Estimates (ICEs) belongs to the Cost Analysis Office (CAO). This paper describes a systematic methodology to be used to select and rank projects in support of the CAO cost research mission.

The paper is in two parts. Part 1 identifies a large list of candidate cost research projects, and their descriptions, which are divided into four categories: (1) Databases; (2) Cost Estimating Relationships (CERs) and Methods; (3) Models; and (4) Special Studies. Part 2 of the paper describes in detail a process for selecting the "best" set of projects within limited funding constraints using the Analytic Hierarchy Process (AHP) in conjunction with an Integer Linear Program (ILP). The process entails three major steps: (1) developing and evaluating a multi-criteria hierarchy; (2) determining the relative value of each potential project using the AHP method, where the relative values or "priorities" are based on factors such as urgency, affordability, payoff, and feasibility; and (3) selecting the "best" projects using ILP.

The decision process presented in this paper is a unique application of operations research decision theory which could be tailored to many decision-making tradeoffs that the DoD faces. A spin-off of this effort could be a useful tool for program management problems that transcend cost research planning.

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1
INTRODUCTION

The Army Strategic Defense Program is the implementation of the Strategic Defense Initiative (SDI) for the purposes of developing capabilities to protect U.S. forward deployed forces, power projection forces, friends and allies, and the United States against ballistic missile attacks. Such protection involves surface and space based systems and elements to ensure continuous global detection, track, and intercept of ballistic missiles and their associated warheads. U.S. Army efforts include coordinating with the Strategic Defense Initiative Organization (SDIO); conducting research, development, and acquisition of strategic and tactical systems to include Theater, National, and Global Missile Defense elements; and developing appropriate technology bases. The role of research, development, and acquisition of these systems is the responsibility of the U.S. Army Space and Strategic Defense Command (USASSDC). Within USASSDC, the responsibility for developing methodology, models, databases, and validating cost estimates of these systems belongs to the Cost Analysis Office (CAO).

CAO is involved in cost estimating in all phases of the SDI architectures -- Global Protection Against Limited Strikes (GPALS), Army National Missile Defense (ANMD), and Army Theater Missile Defense (ATMD). Figure 1-1 illustrates the integrated system concept of GPALS.

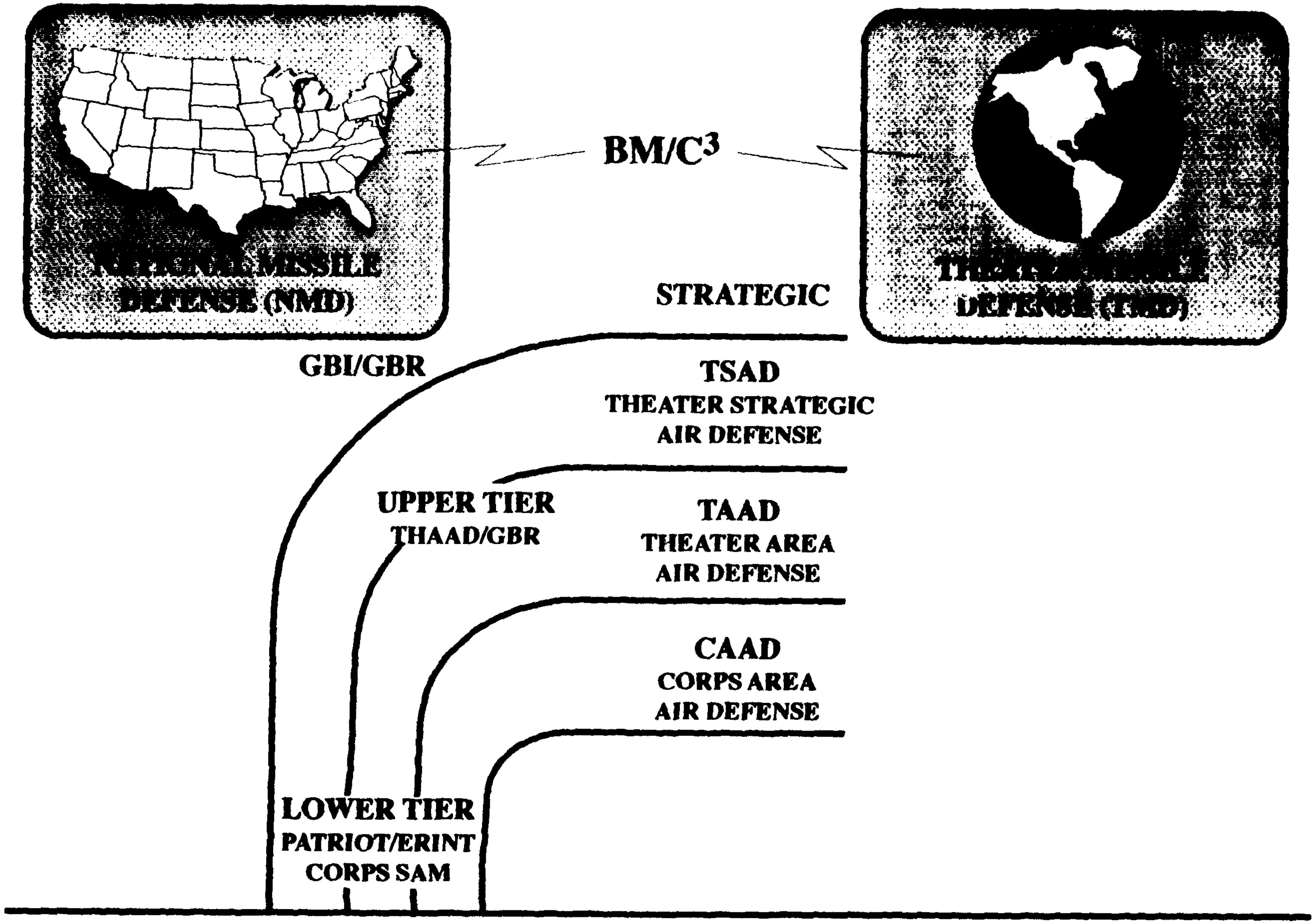

Figure 1-1 Integrated System Concept - GPALS

The systems associated with GPALS, NMD, and TMD can be further subdivided into near-term and far-term systems as shown in the Table 1-1:

Table 1-1
Strategic and Theater Systems

Systems	Strategic		Theater	
	Near-Term	Far-Term	Near-Term	Far-Term
GBR - NMD	X			
GSTS	X			
GBI	X			
CCE	X			
ERINT			X	
PATRIOT P3I			X	
ARROW/ACES			X	
THAAD			X	
CORPS SAM			X	
GBR - TMD			X	
ATOC			X	
Free Electron Laser (FEL)		X		
Neutral Particle Beam (NPB)		X		
Electrothermal Chemical Gun				X
Laser Radar				X

The technology development program associated with the above systems can be subdivided between the necessary subsystem areas associated with sensors, kinetic and directed energy weapons, and BM/C^3. Table 1-2 shows this mapping:

Table 1-2

USASSDC Technology Areas

Technologies	USASSDC System Areas			
	Sensors	Kinetic Energy Weapons (KEW)	Directed Energy Weapons (DEW)	BMC^3
Advanced Materials/Materials Processing		X	X	
Advanced Signal Processing/Computing	X	X	X	X
Directed Energy			X	
Low Observables Technology	X			
Microelectronics/Photonics	X			X
Advanced Propulsion Technologies		X		
Space Technology	X	X	X	
Advanced Manufacturing Technologies	X	X	X	X

The remainder of this report is contained in two sections. Section 2 presents the recommended projects and their description, Section 3 discusses the methodology used to select and rank the chosen projects. Section 4 presents a schedule of projects selected from Section 2 by applying the methodology described in Section 3.

2
IDENTIFICATION OF REQUIREMENTS

This section presents the candidate projects and a brief description of each.

2.1 CANDIDATE PROJECTS

Candidate projects were divided into four basic categories: (1) databases, (2) Cost Estimating Relationship (CERs) and methods, (3) major computer models, and (4) special studies. The selection of candidate projects was done by a combination of interview with experts within Tecolote and by reviewing any pertinent literature, such as the Army Technology Base Master Plan[1]. Please note that projects, programs, and/or technologies managed by USASSDC that might be expected to be listed may simply be excluded because of recent cost research efforts; e.g., Extended Range Interceptor (ERINT), Airborne Optical Adjunct (AOA), Airborne Surveillance Testbed (AST), and PATRIOT PAC II which are currently in process as factbooks. The candidate projects selected are as follows:

Databases

- Fact Books
  - High Endoatmospheric Interceptor (HEDI) Subsystem
  - Exo-Endoatmospheric Interceptor (E^2I)
  - Ground Surveillance and Tracking Subsystem (GSTS)
  - Exoatmospheric Reentry Vehicle Interceptor Subsystem (ERIS)
  - Ground Based Interceptor (GBI)
  - Aegis
  - Cheyenne Mountain
  - Anti-Satellite (ASAT) System
  - Theater High Altitude Area Defense (THAAD)
  - Ground Based Radar (GBR)
  - Technology Programs
  - Light Exoatmospheric Projectile (LEAP)
- Cost Estimating Handbook
- Ada Software

[1]Army Technology Base Master Plan, Volumes I and II, February 1992.

Cost Estimating Relationships (CERs) and Methods

- Infrared Focal Plane Array Seekers
  - Telescope
  - Signal Processor
  - Detection Arrays
  - Dewar/Cryostat
  - Window Cooling
  - Radome Materials
- Visible Seekers
- Advanced Solid Propellants
- Battle Management/Command, Control and Communications (BM/C^3)
  - Command and Control Element (CCE)
  - Ground Entry Point (GEP)
  - Engagement planning (EP)
- Hypervelocity Gun (HVG) Technology
- Directed Energy Weapons
  - Free Electron Laser (FEL)
  - Chemical Laser
  - Neutral Particle Beam (NPB)
  - Pointing, Tracking, and Retargeting
- Materials Cost Impacts
- Warheads/Lethality Enhancement Devices (LED)
- Launchers
- Investment Items
- Integration of Cost and Technical Risk Factors
- System Engineering and Integration (ST&E) Function Point Analysis

Models

Radar Engineering and Cost Tool (REACT) Enhancements
System Trades Architecture Cost Model (STACM) Enhancements
Automated Cost Estimating Integrated Tools (ACEIT) Libraries
BM/C^3 GEP Engineering and Cost
BM/C^3 EP Engineering and Cost
BM/C^3 Command Control Element (CCE) Engineering and Cost
System Test and Evaluation (ST&E) Life Cycle Cost Trade-off Model

Special Studies

Software Sizing Risk Analysis
Selected Acquisition Report (SAR) Cost Growth
BM/C^3 Sizing
Microelectronics Sizing
Analog Selection
Software Function Point Analysis
Artificial Intelligence -- AI/Expert Systems
Linear Discriminators

2.2 PROJECT DESCRIPTIONS

This section includes a short description of the proposed effort that would be conducted under the various projects.

2.2.1 DATABASES

2.2.1.1 Factbooks

The development of Factbooks will document the threat requirement, mission, heritage evolution, technical contract program, and cost history data. This would provide "lessons learned" and reference information, as well as provide additional cost data for use in the development of Cost Estimating Relationships (CERs), Cost-to-Cost (CTC) factors, analogs, and other vital cost and performance information to enhance future projections.

HEDI (E^2I)

The HEDI (E^2I) program is a source of valuable information. Recently canceled, the information may be unavailable if not applied soon. Our subcontractor, CRC, is well qualified by their direct involvement to efficiently and effectively support this effort.

GSTS

Relevant hardware (especially sensor) and software data would be provided in the areas of missile components.

ERIS (GBI)

This program is the GPALS/NMD interceptor. Our subcontractor, SPARTA, has supported GBI for years and would be a valuable resource on this project. It should include the Homing Overlay Experiment (HOE), ERIS, Ground Based Interceptor Experimental (GBI-X), and GBI.

AEGIS

The U.S. Navy AEGIS Weapon System is a sophisticated configuration of integrated hardware and software subsystems. (The word "aegis" which has associations with Greek and Roman mythology, means "protection" or "defense".) It embodies several sensors, five or more weapons, and BM/C^3 for air, surface, and antisubmarine warfare. It is a relevant analog for many aspects of SDI.

AEGIS represents the single-most, complex system integration and system test data point prior to SDI. As such, there is direct application potential in the areas of System Engineering and Integration (SE&I), BM/C^3I, software, testing of BM/C^3I and complex integrated strategic weapon systems, and many other technical and cost components of a complex weapon system.

Cheyenne Mountain

The BM/C^3 (C^2E) program is, in part, a modification to the Cheyenne Mountain AFB Command Center. There are currently five upgrades in process. We need to recognize and understand that baseline for the further enhancements to accomplish the Strategic Defense Initiative (SDI).

ASAT

Relevant hardware and software data would be provided especially in areas of missile components (e.g., boosters and sensors).

THAAD

Relevant hardware and software data would be provided; especially in the areas of missile components, TMD sensors, launcher, and Tactical Operations Center.

Ground Based Radar (GBR)

A reference that captures the evolution of USASSDC radar concepts from the Terminal Imaging Radar (TIR) and GBR-X up to the current GBR-TMD and GBR-NMD.

Technology Programs

The development of either an overall Technology Program Factbook or a series of specific Technology Factbooks would be useful to document the technical, programmatic, schedule, research efforts, contract, and cost data for the various Kinetic Energy Weapons (KEW), Directed Energy Weapons (DEW), Survivability Lethality and Kill Technology (SLKT), and component technology programs. This would provide useful analog and potential CER cost data for use in future cost and budget estimates. In addition, these document(s) would provide data for the CARD development and information on the potential impact of "leveraging" from the technology programs.

LEAP

The development of the Light Exoatmospheric Projectile (LEAP) Factbook would provide information regarding the Army LEAP and endo-leap programs on technical programmatic, schedule, research activities, tests, contracts, and cost data. This information would be useful in the development of small/miniature components and projectile capabilities. Information regarding the Air Force LEAP program might also be included.

2.2.1.2 Cost Estimating Handbook

The development of a Cost Estimating Handbook would give a ready CER, factor and analog reference for cost analysts. It would be organized pursuant to the US Army "Big

Six" or "Big Three" cost element structures (CES) for all life cycle phases. Other cost documents would be used in addition to cost databases, cost research reports, and other literature to provide the various CERs, factors, and analogs. The initial construction would be heavily dependent on existing cost research; while in the future, original research might be conducted to enhance the handbook. This handbook might be similar in context to the Unmanned Spacecraft Cost Model (USCM) series or the Air Force Systems Command Cost Estimating Handbooks.

2.2.1.3 Ada Software

Develop a database of Ada software projects of interest to USASSDC. This would include cost and technical parameters such as size, effort, complexity, and others.

2.2.2 CERs AND METHODS

2.2.2.1 Infrared, Focal Plane Array Seekers

This technology is being implemented in the GBI and THAAD interceptors. There are many programs in all three Services that are pursuing "second generation" focal planes. Data collection would be for methodology improvement and surveys of other estimating techniques for crosscheck capability. The components include telescope, signal processor, detection arrays, dewar/cryostat, window cooling, and radome materials.

2.2.2.2 Visible Seekers

Many USASSDC interceptor systems are characterized by visible seekers to supplement the target acquisition function performed by IR seekers. This research task will identify and collect data on current visible seeker and sensor systems and to develop CERs.

2.2.2.3 Advanced Solid Propulsion

Current solid rocket motor technology is well characterized by current CERs. However, advanced features such as insensitive munitions and gels need to be researched.

2.2.2.4 BM/C^3 CCE

A cost estimating reference for the Command and Control Element of strategic defense architectures. This will include analogous data and other relevant cost estimating

methodology. Evolving processor technology limits the "shelf life" of CERs and requires frequent updates.

2.2.2.5 BM/C^3 Ground Entry Point

A cost estimating reference for Satellite and Interceptor Ground Entry Points (GEP). This study will include analogous data, CERs, and other relevant cost estimating methodologies.

2.2.2.6 BM/C^3 Engagement Planning

A cost estimating reference for Engagement Plan or (Battle Management) systems. This will include analogous data, CERs, and other relevant cost estimating methodologies.

2.2.2.7 Hypervelocity Gun Technology

Updating of the study from Task Assignment 91-003, titled CR-0542, "Hyper Velocity Gun (HVG) Technical Report and Cost Methodology", November 1991, would include data collection and an update of the CERs.

2.2.2.8 Directed Energy Technologies

The development of Directed Energy CERs and methods would be useful in assisting the cost analyst in the development of leap ahead technologies under consideration in strategic and TMD scenarios. Items that might be included are Free Election Laser (FEL), chemical laser, Neutral Particle Beam (NPB), Pointing, Tracking, Retargeting, etc. Directed Energy Weapons (DEW) will continue to be examined and possibly be the weapons of the future. Methodologies need to be improved to support existing estimating requirements.

2.2.2.9 Material Cost Impacts

Task 91-007 identified a number of new materials and potential applications to USASSDC systems. Within the task, "IR Windows and Structures" were pursued for CER development. There are many follow-on candidates from that list (including updating the list or adding data to update the Window CER).

2.2.2.10 Warheads/LEDs

The development of estimating CERs and methods for warheads and Lethality Enhancement Devices (LEDs) is an area that has not been sufficiently examined. Very few CERs exist and most estimates are of an analog nature. This is an excellent opportunity to produce a comprehensive warhead/LED cost estimation document for use throughout DoD. The TMD environment will include fragmentation type warheads in addition to the kinetic kill LED methods and should be examined.

2.2.2.11 Launchers

The development of updated launcher CERs and data would be very timely since many of the CERs date back to 1983. The requirements of various TMD systems include "roll-on, roll-off", C-130 capability, and volume and weight constraints. The Army needs new types of launchers, lighter materials (e.g., Boron Epoxy), smaller platforms (e.g., 5 ton), stabilization, blast shields, erection systems, and data interchange.[2]

2.2.2.12 Investment Items

This effort should be accomplished to develop CERs, factors, and analogs for various Investment/Production/Procurement Items. A databook and/or collection of investment cost element methods in a document would be useful for quick reference. Data collection and literature research should be conducted to provide a comprehensive listing. New CERs and factors could be developed using the revised and stratified databases.

2.2.2.13 Integration of Risk Factors

The general methodologies dealing with Risk Analysis are well defined but typically are applied in a one-dimensional way (i.e., cost, technical, or schedule). The interrelationships between cost risk and technical risk are intuitively clear, but methodologies to capture the total risk impact (addressing the statistical dependency between the two) are limited. This proposed research effort would develop a rigorous applied methodology to derive risk factors which measure the effects of correlated cost and technical risk postures.

[2] e.g., Enhanced Position Location Reporting System (EPLRS), and Joint Tactical Information Distribution System (JTIDS), etc.

2.2.2.14 SE&I Function Points

Study the application of function point counting to the problem of estimating the cost of System Engineering and Integration (SE&I). This task will include data collection and methodology development.

2.2.3 MODELS

2.2.3.1 Radar Engineering and Cost Tool (REACT) Enhancements

This is a useful trade study model. There are a number of further developments (input/outputs, analysis features, testing, and documentation improvements) that are recommended.

2.2.3.2 STACM Enhancements

This top-level trade study model is currently populated with TMD systems. NMD systems can be added to the templates and libraries. Putting the model into operation may identify user defined improvements.

2.2.3.3 ACE IT Libraries

A library of USASSDC CERs and factors could be loaded into ACE IT for productivity in estimating and documentation. This could also include the methods such as those described in 2.2.1.2 and all of 2.2.2.

3.2.3.4 GEP Engineering & Cost

Development of a GEP Engineering and Cost Model would be useful in Independent Cost Estimates and architecture studies.

2.2.3.5 ST&E Life Cycle Cost (LCC) Trade-off Model

Building upon the ST&E Cost Guide proposed for the FY93 efforts would be the development of a stand alone automated ST&E cost and trades model. The model might consist of some of the features of the STACM, REACT, and other automated estimating models. Ideally it would have an ST&E cost library and database attached whereby selection of ranges, targets, and launch vehicles could be conducted. The input of quantities and time-phased schedules would produce a time-phased estimate in constant and escalated dollars.

An excursion and optimization capability and a top-level flow chart or network (automatically produced) might be possible. The model would be extremely useful to project offices and test organizations.

2.2.3.6 Engagement Planning Engineering & Cost Model

It would be useful to develop an Engagement Planning (EP) Engineering and Cost Model for Independent Cost Estimates and architecture studies.

2.2.3.7 CCE Engineering & Cost

The development of a Command and Control Element (C^2E) Engineering and Cost Model would be useful in Independent Cost Estimates and architecture studies.

2.2.4 SPECIAL STUDIES

2.2.4.1 Software Sizing Risk Analysis

Develop a study of software sizing and its impact on software cost estimates. Develop a means to quantify the risk in software sizing estimates.

2.2.4.2 SAR Cost Growth

The historical track of cost change (variance) for major Department of Defense (DoD) programs is captured in the Selected Acquisition Report (SAR). This data, when analyzed in the context of the SAR variance analysis statements, provides an excellent source of program cost change over a relatively long and continuous time frame. This proposed research effort would develop expected cost change (growth) factors for future programs based on Service, Weapon type, system complexity, etc. These factors can be used for cross-checking the more rigorously developed risk (TRACE/TRACE-P) estimates.

2.2.4.3 BM/C^3 Sizing

The data collection and research of BM/C^3 requirements, performance, technical, software, staffing and other interrelationships could be useful in assessing the realism of the Cost Analysis Requirements Document (CARD) baseline.

2.2.4.4 Microelectronics Sizing

The development of a study of microelectronic sizing methodologies should be performed to include the development of new methods for sizing the quantity and type of microelectronics components.

2.2.4.5 Analog Selection

Development of an analytic method for selecting and scaling the best analog subsystem/component to the desired item, based on that item's technical and performance characteristics. This methodology could be used when there is not enough relevant data to apply high quality CERs and for cross checks of other estimating methodologies.

2.2.4.6 Software Function Point Analysis

Development of a study of the application of Software Function Point (FP) Analysis techniques to USASSDC projects. Collect and analyze FPs on selected projects.

2.2.4.7 AI/Expert Systems

Investigate generating AI/expert system rules from numerical data using fuzzy logic calculus. Recent advances in Europe and Japan applying fuzzy logic calculus to engineering design and estimating problems indicate that these techniques might be useful in cost estimating where there is little relevant data. Also, obtain and evaluate recent commercial AI/expert system literature and packages for potential application to the USASSDC data environment.

2.2.4.8 Linear Discriminators

Discriminant analysis is a multivariate statistical technique can be used to develop combinations of sets of variables, which are criteria for group differentiation. A linear combination of such variables is called a "linear discriminant function". This proposed research effort would develop linear discriminant functions to be used for classifying or assigning given "products" to a specific group. For example, a discriminant function could be developed to classify a proposed program schedule as a "high", "nominal", or "low" risk schedule. Similarly, functions could be developed for assigning or classifying a cost estimate within a range of "not probable", "probable", or "most probable".

3
METHODOLOGY

3.1 DECISION TOOL CONCEPT

The process of selecting the "best" set of projects within limited funding constraints can be a complicated resource allocation problem. Unfortunately, almost every real world decision involves multiple objectives. Use of traditional optimization techniques, such as linear programming (LP), are limited to optimizing a single objective subject to a number of constraints. Thus, a pure LP approach to the resource allocation problem often appears to be "forced". There is a strong likelihood that senior management will (rightfully) feel uncomfortable with the analysis and not make proper use of it in their decisions. Instead, they will tend to ponder how to evaluate the tradeoffs between the pros and cons of each potential project with respect to each of their "true" objectives, which will be some mixture of quantitative and qualitative considerations.

The Analytic Hierarchy Process[3] (AHP) is a method that formally structures multi-objective tradeoffs. Considering the pros and cons, the decision maker structures the organization's primary objectives, sub-objectives, and so on into a hierarchy. Using the AHP method to evaluate the hierarchy produces a set of weighted numerical averages which reflect the decision maker's relative priorities. Thus, each potential project has a numerical measure that represents its overall value with respect to all the identified selection criteria (qualitative as well as quantitative). Using these measures as the basis of an objective function, an Integer Linear Program (ILP) can be used to determine the "best" selection of projects to undertake in a given time period, subject to budgetary and other constraints.

The remainder of this section describes the details of the process used in developing the research road map project selection for USASSDC/CAO. In brief, the process entails three major steps: (1) developing and evaluating a multi-criteria hierarchy, (2) determining the relative value of each potential project using the AHP method, and (3) selecting the "best" projects using ILP. The selection of potential projects is discussed in Section 4.

---

[3] Saaty, T.L., The Analytic Hierarchy Process, McGraw-Hill book Co., 1980.

3.2 MULTI-CRITERIA HIERARCHY

In providing cost estimating and validation to USASSDC, the CAO depends on research to develop the databases, Cost Estimating Relationships (CERs) and methods, detailed computer models, as well as special studies to support their estimates. In choosing projects for these research areas, CAO needs to consider each project's urgency, affordability, payoff, and feasibility of successful completion. Figure 3-1 shows the AHP hierarchy built to represent these primary considerations. In addition, pairwise comparisons were made to derive the relative priorities for project urgency, payoff, and feasibility by using qualitative rating scales varying from very low (VLO) to very high (VHI). Affordability was rated using a set of expected cost ranges (e.g., $50 - 100K). The number below each name in Figure 3-1 is the relative priority[4] of that item to the other items at the same level in the hierarchy. For example, 0.1102 is the relative priority of databases with respect to CERs/methods, models, and special studies. Note that the sum of the values at the same level in the hierarchy are equal to one.

3.3 PROJECT RELATIVE VALUE

The relative values or priorities calculated for each project are determined by evaluating the project at the urgency, affordability, payoff, feasibility level of the hierarchy. For example, a database project might be very urgent, cost $75K, have a nominal payoff, and have a high feasibility of successful completion. In words, the relative value computation is as follow:

$$Relative\ Value = Database * (Urgency * HI + Afford * (50 - 100K) + Payoff * NOM + Feasible * HI)$$

Referring to Figure 3-1, Analytical Hierarchy Process (AHP) Prioritization Schematic, the above word formula gives the following numerical value:

$$RelativeValue = 0.1102*(0.2704*0.2635+0.3214*0.0179+0.2869*0.0764+0.1222*0.2635) = 0.01444968$$

[4]Mathematically, the priorities are the normalized eigenvectors of the principal eigenvalue from the reciprocal matrix of ratio scale pairwise comparisons.

Table 3-1 contains the relative values for the potential projects considered in this evaluation. The commercial software package *Expert Choice* by Decision Support Software, Inc. was used to perform the AHP calculations.

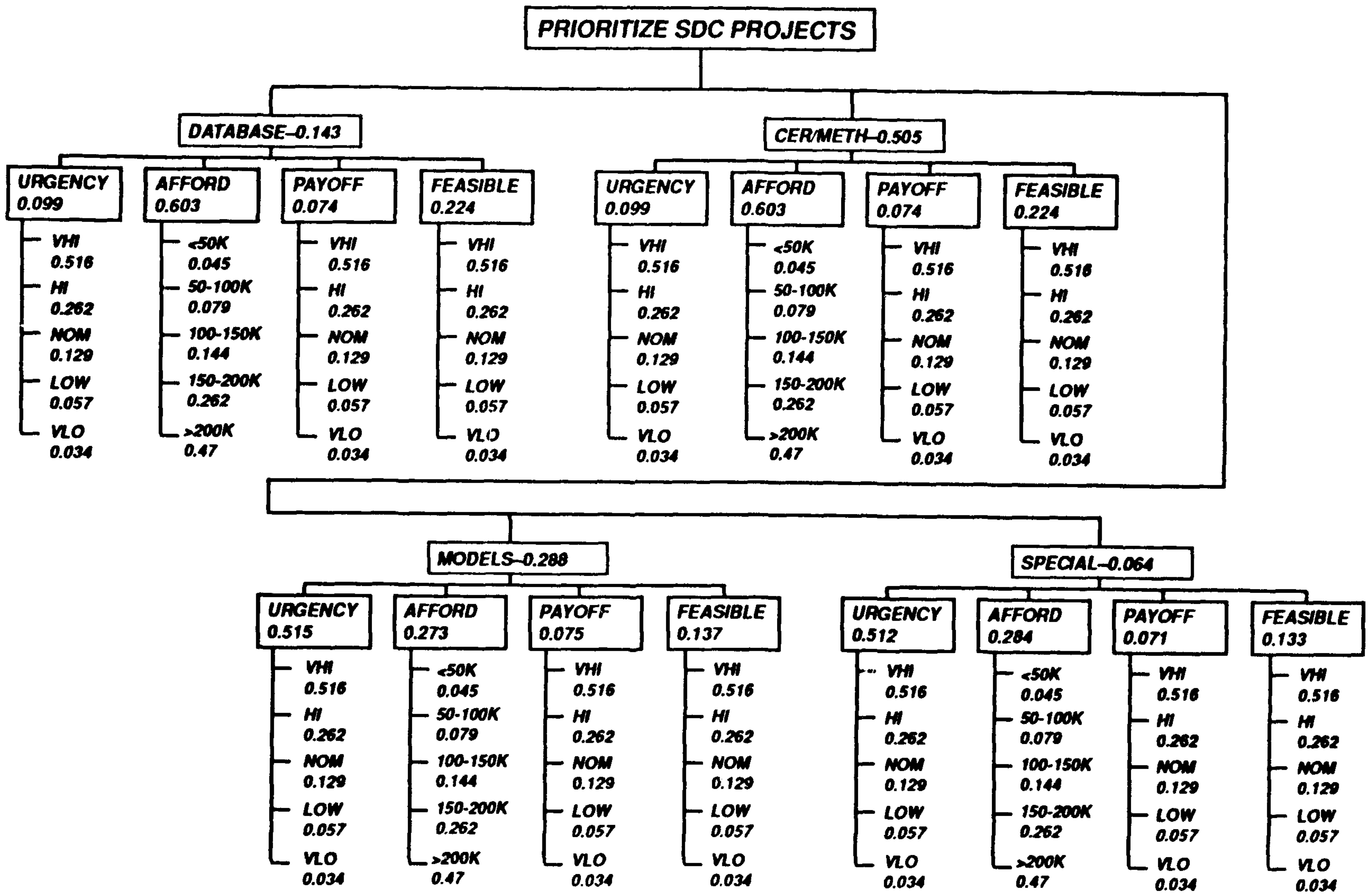

Figure 3-1 Analytical Hierarchy Process (AHP) Prioritization Schematic

TABLE 3-1

PROJECT RELATIVE VALUES

PROJECTS	URGENCY 0.02979808	AFFORD 0.03541828	PAYOFF 0.03161638	FEASIBLE 0.01346644	RELATIVE VALUE
DATABASES					
Factbooks					
HEDI (E2I)	VHI	50-100K	VHI	VHI	0.04369799
GSTS	LOW	50-100K	NOM	HI	0.00798648
ERIS (GBI)	VHI	50-100K	VHI	VHI	0.04369799
Aegis	VHI	50-100K	VHI	VHI	0.04369799
Cheyenne Mtn.	NOM	50-100K	NOM	VHI	0.01307060
ASAT	VHI	50-100K	VHI	VHI	0.04369799
THAAD	NOM	50-100K	NOM	VHI	0.01307060
GBR	LOW	50-100K	NOM	HI	0.00798648
Technology Programs	NOM	50-100K	HI	HI	0.01478988
LEAP	NOM	50-100K	NOM	HI	0.00887446
Cost Est. Handbook	HI	100-150K	VHI	VHI	0.03887916
ADA S/W	NOM	50-100K	HI	HI	0.01478988
SCADS	HI	50-100K	HI	HI	0.02036510
Hazard Waste Handbook III	VHI	50-100K	VHI	VHI	0.04369799

TABLE 3-1

PROJECT RELATIVE VALUES (Cont'd)

CERs/METHODS	URGENCY 0.016375424	AFFORD 0.19463984	PAYOFF 0.17374664	FEASIBLE 0.7400432	RELATIVE VALUE
IR FPA SEEKERS					
TELESCOPE	HI	<50K	NOM	HI	0.08468242
SIGNAL PROCESSOR	VHI	50-100K	NOM	HI	0.13043350
DETECTION ARRAYS	VHI	50-100K	NOM	HI	0.13043350
DEWAR/CRYOSTAT	HI	<50K	NOM	HI	0.08468242
WINDOW COOLING	HI	<50K	HI	NOM	0.13034420
RADOME MATERIALS	NOM	<50K	NOM	NOM	0.14019779
VISIBLE SEEKERS	VHI	50-100K	NOM	HI	0.13043350
ADV. SOLID PROP	HI	50-100K	VHI	HI	0.16605513
BM/C3 CCE	LOW	50-100K	LOW	HI	0.03871173
BM/C3 GEP	LOW	50-100K	LOW	HI	0.03871173
BM/C3 EP	LOW	50-100K	LOW	HI	0.03871173
HV GUN TECHNOLOGY	NOM	<50K	NOM	LOW	0.03799246
DIRECTED ENERGY					
FREE ELECTRON LASER	LOW	<50K	LOW	LOW	0.02793494
CHEMICAL LASER	LOW	<50K	LOW	LOW	0.02793494
NEUTRAL PART. BEAM	VLO	<50K	VLO	LOW	0.02516743
POINT, TRACK, RETARG	NOM	<50K	NOM	LOW	0.03799246
MATRL COST IMPACTS	HI	<50K	HI	NOM	0.10334420
WARHEADS/LEDS	HI	<50K	HI	NOM	0.10334420
LAUNCHERS	NOM	50-100K	HI	HI	0.08127726
INVESTMENT ITEMS	HI	50-100K	HI	VHI	0.13497542
INTEGR. RISK FACTORS	HI	<50K	HI	VHI	0.14025016
SE&I FUNCTN POINTS	NOM	50-100K	NOM	HI	0.04876926
BELOW THE LINE COSTS					
SEPM	HI	50-100K	VHI	VHI	0.18911487
GOVT vs NON-GOVT	HI	<50K	HI	NOM	0.10334420
TOOLING	HI	<50K	HI	NOM	0.10334420
RDT&E	VHI	50-100K	HI	HI	0.16294149
SURVIVABILITY	HI	50-100K	HI	HI	0.11191567
TEST COSTS	VHI	100-150K	HI	HI	0.18748558
DEW PROTO TO PROD	NOM	100-150K	NOM	HI	0.07331334
MADCAP	HI	50-100K	HI	HI	0.11191567
MISSILE ATTITUDE CNTL	VHI	50-100K	VHI	NOM	0.20323474
ENVIRONMENTAL I	VHI	50-100K	VHI	VHI	0.24014069
ENVIRONMENTAL II	VHI	50-100K	VHI	VHI	0.24014069
ENVIRONMENTAL III	VHI	100-150K	VHI	VHI	0.26468478
O&S CERs	VHI	50-100K	VHI	HI	0.21708095
PROTO-PROD FACTORS	VHI	100-150K	VHI	HI	0.24162503

TABLE 3-1

PROJECT RELATIVE VALUES (Cont'd)

MODELS	URGENCY 0.0559728	AFFORD 0.0665298	PAYOFF 0.0593883	FEASIBLE 0.0252954	RELATIVE VALUE
REACT ENHANCEMENTS	NOM	<50K	NOM	VHI	0.02635481
STACM ENHANCEMENTS	NOM	<50K	NOM	VHI	0.02468682
ACEIT LIBRARIES	VHI	50-100K	HI	VHI	0.06357704
GEP ENGRG. & COST	VHI	100-150K	VHI	HI	0.08258980
ST&E LCC TRADES	HI	100-150K	HI	HI	0.02778136
EP ENGRG. & COST	VHI	100-150K	VHI	HI	0.02505922
CCE ENGRG. & COST	VHI	100-150K	VHI	HI	0.02505922
SCATS	LOW	<50K	NOM	VHI	0.02468682
PICES SUPPORT	NOM	50-100K	NOM	VHI	0.02455186
ACEIT SUPPORT	VHI	50-100K	VHI	VHI	0.08208244
GUARDIAN MODEL	LOW	100-150K	LOW	HI	0.02162146
DEFENDER MODEL	LOW	100-150K	NOM	VHI	0.03127327
SENSOR-INTERCEPTOR COST/PERFORMANCE TRADE-OFF MODEL	HI	150-200K	HI	HI	0.05449380
ENVIRONMENTAL II	VHI	50-100K	VHI	HI	0.07420039
ENVIRONMENTAL III	VHI	50-100K	VHI	HI	0.07420039
MODIBLE RADAR ICE	HI	150-200K	HI	VHI	0.06237584
ACEIT TO BIG 3 FORMAT	VHI	<50K	VHI	VHI	0.08388539
GENERIC INT. MODEL	HI	150-200K	HI	NOM	0.04976103

SPECIAL STUDIES	URGENCY 0.02087488	AFFORD 0.02481208	PAYOFF 0.02214868	FEASIBLE 0.00943384	RELATIVE VALUE
S/W SIZING RISK ANAL	VHI	<50K	VHI	NOM	0.02658014
SAR COST GROWTH	HI	<50K	NOM	HI	0.01079505
BM/C_3 SIZING	NOM	<50K	NOM	HI	0.00688936
MICROELEX SIZING	NOM	50-100K	NOM	NOM	0.00445188
ANALOG SELECTION	NOM	<50K	NOM	VHI	0.00982894
S/W FUNCT PT ANALYSIS	HI	50-100K	NOM	HI	0.01012264
AI/EXPERT SYSTEMS	LOW	<50K	HI	LOW	0.00836511
LINEAR DISCRIMINATORS	LOW	<50K	NOM	LOW	0.00422109
ARMY REVIEW PROCESS	HI	<50K	HI	VHI	0.01787865
LEAP ARCH. ANALYSIS	NOM	50-100K	HI	HI	0.01036097
WBS & CCDR PLANNING	NOM	<50K	NOM	VHI	0.00982894
ARMY SPACE APPLICATN	HI	150-200K	VHI	HI	0.02722482
SMALL PRGM COST RES	NOM	50-100K	HI	NOM	0.00859590
LIQUID/GEL PROPELLANT	NOM	<50K	HI	NOM	0.00926831

3.4 PROJECT SELECTION

The relative values for each project can, in a simplistic sense, be viewed as representing a measure of "profit" that would accrue to CAO should the project be undertaken. Of course, it is much more since the relative value represents the combination of multiple criteria, in a quantified proportion, integrated into one number for each project. These project relative values can then be utilized in an integer linear program in the same way that profit is utilized as the objective function of a linear programming maximization. But now the objective function represents many objectives.

The choice variables in the objective function are constrained to be binary (0 or 1). In other words, a project is chosen or it is not. Neither multiple copies nor fractional parts of a project can be chosen as "might occur" in a linear program. Another set of constraints have to do with the total budget available over any time period, and how much of it should be allocated to each major research area. In our analysis, the total budget was not a fixed number but rather was a range (e.g., $600-800K for a single fiscal year). The relative amount of the total budget allocated to any single research area was treated as a midpoint percentage range of the total budget range. For example, the database research area might be constrained to be between 10% and 20% of a total budget of $700K (i.e., $70-140K). Other constraints could easily be added, but were not for this analysis. In our analysis the budget constraints were set as follows:

Total Budget	$600 - 800K per fiscal year
Database	at least 15% of total budget midpoint
CERs/Methods	40 - 60% of total budget midpoint
Models	at least 25% of total budget midpoint
Special Studies	at least 5% of total budget midpoint

The *What's Best* spreadsheet add-in by Lindo Systems, Inc. was used to perform the ILP selection of projects. The spreadsheet used was *Excel 4.0* by Microsoft Corporation.

In summary, the multicriteria approach consists of using AHP to derive measures of value for the proposed research projects. This allows many objectives to be combined into a composite measure of values to be maximized. Then ILP is used to chose the best set of

projects subject to a set of budget constraints. Since the demands on CAO are not static, this process can be repeated as often as necessary, changing judgments in the AHP model or adding new constraints whenever external events make them appropriate. Since the analysis utilizes commercial software, the files associated with the analysis can be saved and, thus, are available to update the project choice list on an as needed basis.

4
RESEARCH ROADMAP

Projects were selected using the methodology described in Section 3. The selections were subdivided into near-term and far-term projects. Near-term was defined as the next two fiscal years, and far-term was years three through five. Time-phasing was accomplished by setting fiscal year budget thresholds within the ILP. In particular, the next fiscal year's budget was constrained to be between $600K and $800K. The second fiscal year's budget was constrained to $1200-1600K. The full five year budget was constrained between $3000-$4000K. Tables 4-1, 4-2, and 4-3 show the scheduling of near-term and far-term projects.

Table 4-1

Near-Term Projects - First Fiscal Year

Databases	**Estimated Cost**
ASAT	50-100K
ERIS (GBI)	50-100K
CERs/Methods	
TELESCOPE	< 50K
DEWAR/CRYOSTAT	< 50K
WINDOW COOLING	< 50K
ENVIRONMENTAL I	50-100K
Models	
REACT Enhancements	< 50K
STACM Enhancements	< 50K
ACEIT SUPPORT	50-100K
ACEIT TO BIG 3 FORMAT	<50K

Table 4-2
Near-Term Projects - Second Fiscal Year

Databases	**Estimated Cost**
ERIS	100-150K
CERs/Methods	
SEPM	50-100K
ADVANCED SOLID PROPELLANTS	50-100K
MATERIAL COST IMPACTS	< 50K
WARHEADS/LEDS	< 50K
ENVIRONMENTAL	50-100K
Models	
ACEIT Libraries	50-100K
SCATS	< 50K
Special Studies	
WBS AND CCDR PLANNING	< 50K

Table 4-3
Far-Term Projects - Fiscal Years Three - Five

Databases	**Estimated Cost**
Aegis	50-100K
Hazardous Waste Handbook	50-100K
CERs/Methods	
Signal Processor	50-100K
Detector Arrays	50-100K
Visible Seekers	50-100K
Pointing, Tracking, Retargeting	<50K
Investment Items	50-100K
Integration Risk Factors	<50K
Govt Vs Non-Govt	<50K
Tooling	<50K
Rdt&E	50-100K
Missile Attitude Control	50-100K
Environmental	50-100K
O&S Cers	50-100K
Prototype-To-Production Factors	100-150K
Hypervelocity Gun Technology	<50K
Models	
GEP Engineering & Cost	100-150K
PICES Support	50-100K
Environmental	50-100K
Special Studies	
S/W Sizing Risk Analysis	< 50K
SAR Cost Growth	< 50K
Liquid/Gel Propellants	< 50K

The suggested lists and evaluation techniques are presented as an approach to the CAO's long-range planning. Tecolote's objective was to present the USASSDC's requirements, priorities, and budget constraints as recognized by us during this task. The next step would require feedback from surveys or interviews with key USASSDC CAO personnel. That information will form the foundation for calibrating the "real plan" based on a consensus (using AHP) and sorting (using ILP) of CAO's actual priorities. This would initiate an efficient process for updates as priorities change.

This decision process presented herein is a unique application of operations research decision theory. This multi-criteria objective function, using AHP for setting coefficients and applying constraints with linear programming, has been shown to be theoretically valid. We are not aware of previous practical applications It should be noted that this process could be tailored to many decision-making tradeoffs that USASSDC faces. Therefore, a spin-off of this task could be a useful tool for program management problems that transcend cost research planning.